High-Resolution Paleoclimate Record based on $\delta^{18}O$ Variations in Speleothems from Central China

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In order to fully understand the causes and mechanisms of recent environmental change, it is necessary to develop a highly detailed and reliable record of past climatic fluctuations. Speleothems collected from limestone caves on the eastern Qinghai-Tibetan Plateau contain a detailed, but as of yet unexplored, record of climate change over the last several glacial-interglacial cycles. In order to assess the suitability of speleothems from this region for paleoclimate reconstruction, we have performed a pilot study on a 36 cm long fossil stalagmite and several modern soda straw stalactites collected from Wanxiang Cave (33°19′ N, 105°00′ E), Gansu Province, China (Figure 1). Wanxiang Cave is an active or "wet" cave with abundant actively forming and fossil speleothems. The study site is located in the Qinling Mountains, a key geographic location on the eastern edge of the Qinghai-Tibetan Plateau and the southwest edge of the Loess Plateau, near the modern limit of the summer monsoon.

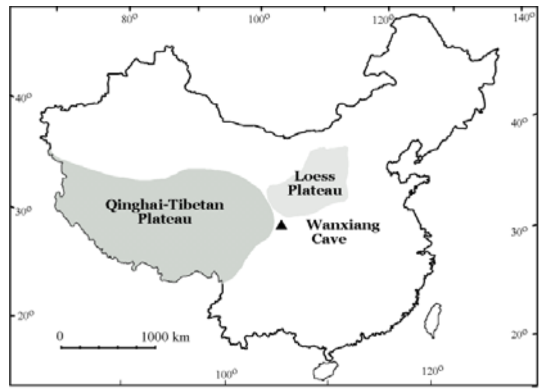

Figure 1. Location Map of Wanxiang Cave

To interpret past stable isotope variations in speleothems, it is necessary to perform a thorough study of the modern carbonate-water system in the cave where they were formed. Under equilibrium conditions, the $\delta^{18}O$ of calcite is a function of the $\delta^{18}O_{dw}$ (dripwater) and temperature. If the $\delta^{18}O$ of both calcite and dripwater can be determined, the cave temperature can be directly calculated from the temperature-dependent fractionation factor between calcite and water (O'Neil *et al.,* 1969). The isotopic composition of cave waters, however, may exhibit complex variations on seasonal or longer time scales, that are related to changes in annual precipitation amount, recharge rates, storm tracks, and evaporation in the epikarst (Bar-Matthews *et al.*, 1996). To interpret $\delta^{18}O$ variations in fossil speleothems, we must show: (1) that the $\delta^{18}O$ of modern speleothems reflects the $\delta^{18}O$ of modern dripwater, and hence, modern precipitation, and (2) that the speleothem calcite was formed in isotopic equilibrium with the water.

We have performed a pilot study on a number of cave waters and actively forming soda straw stalactites collected from Wanxiang Cave to determine the principle controls on the calcite isotopic composition. The mean $\delta^{18}O_{dw}$ in Wanxiang Cave is –9.01 ± 0.54‰. We used data from the Global Network for Isotopes in Precipitation (GNIP) from sites surrounding the Wanxiang Cave region to construct a local meteoric water line. Wanxiang Cave dripwater samples plot directly on the local MWL, suggesting that the $\delta^{18}O_{dw}$ is closely related to $\delta^{18}O$ of precipitation and has not been significantly affected by evaporative processes in the epikarst. The $\delta^{18}O$ of modern soda straw stalactite tips ranges from –6.87 ‰ to –8.36 ‰ (PDB), with the most enriched values found towards the entrance. Using the measured $\delta^{18}O_{dw}$ and $\delta^{18}O_{mc}$ (modern calcite) values from the 4 locations in the deepest part of the cave, and the carbonate paleotemperature equation (Epstein *et al*., 1953; O'Neil *et al*., 1969), the calculated temperatures range from 11.4 to 13.7 ^{o}C. The mean annual temperature in Wudu, is approximately 12-13^{o}C. This suggests that modern speleothems are forming under isotopic equilibrium and that their isotopic composition accurately reflects the mean annual temperature at the surface.

In order to directly calculate past temperatures from the $\delta^{18}O$ values of fossil speleothems, it is necessary to know the $\delta^{18}O$ of the water from which the calcite precipitated, which is directly related to the $\delta^{18}O$ of precipitation at that time. The $\delta^{18}O$ of precipitation at a given locale is affected by several factors, such as surface temperature, amount of precipitation, elevation, source composition, and continentality (Dansgaard, 1964). While there is a strong correlation between $\delta^{18}O_p$ and T (~0.55‰/^{o}C) at mid- to high-latitude sites, the correlation between T and $\delta^{18}O_p$ is much weaker or non-existent in low latitudes due mainly to the dominance of different mechanisms of moisture transport. Oxygen isotopes in precipitation in these areas may be significantly affected by the amount of precipitation in addition to temperature. To assess the suitability of oxygen isotope records preserved in speleothems from central China for use in paleotemperature and paleoprecipitation reconstructions, we have performed a number of multiple regression analyses on GNIP data to try and approximate values of $d\delta^{18}O/dT$ and $d\delta^{18}O/dP$ in modern precipitation near this site. Our preliminary results show that $\delta^{18}O$ of precipitation is positively correlated with temperature in China, and negatively correlated with amount of precipitation. There is, however, statistically significant site-to-site variability in the slopes of these relationships that results from the dependence of $\delta^{18}O_p$ on elevation, latitude, source of moisture, topography, etc. Sites that are influenced more by monsoon precipitation exhibit a negative relationship between $\delta^{18}O_p$ and T, due to the dominance of the amount effect.

One of the speleothems from Wanxiang Cave (a 36 cm-long stalagmite, WXSM-51) was chosen for dating using Uranium-series TIMS methods. The stalagmite was sampled for radiometric dating in six spots. The results indicate that the stalagmite began forming 313 ± 8.4 thousand years ago. Stalagmite growth stopped during the Last Glacial Maximum (LGM), 19.8 ± 0.3 thousand years ago. Six major growth hiatuses observed in the stalagmite indicate that calcite precipitation stopped for extended time periods, possibly due to very cold and/or dry conditions in the region (Gascoyne, 1992). The top 7.5 cm of stalagmite WXSM-51 was sampled for stable isotope analyses (O and C) at a very high-resolution (~300 micron sample width) using a computer controlled micromilling device. We sampled the remainder of the stalagmite using a hand held drill (~2 mm sample width) to provide a coarser resolution, but

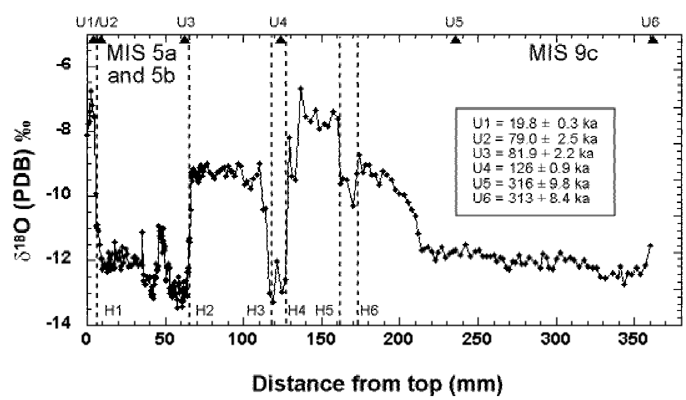

Figure 2. $\delta^{18}O$ data for sample WXSM-51, showing U/Th ages and location of major hiatuses (dashed lines).

complete record of isotopic variability. The preliminary oxygen isotope data show that interglacial periods are characterized by more negative $\delta^{18}O_c$ (calcite) values than glacial periods (Figure 2). The average $\delta^{18}O$ value is –12 ‰ during MIS 5a, –12.5 ‰ during MIS 5e, and -12 ‰ during MIS 9. In contrast, the average glacial $\delta^{18}O$ values are –9 ‰ (prior to Hiatus 2), up to –7 ‰ in the section deposited immediately before Hiatus 4, and –7.4 ‰ during the LGM. In addition, the data delineate several well-defined shifts of up to 2 ‰ during MIS 5a (79,000 and 81,900 years ago), and variations of about 0.5 to 1 ‰ during the continuous period of growth during MIS 9 at the base of the speleothem.

The data suggest that temperature and $\delta^{18}O_c$ are inversely correlated in fossil speleothems from Wanxiang Cave. However, in addition to temperature, oxygen isotopic variations may reflect changes in mean annual precipitation, the amount of evaporation in the epikarst, or atmospheric circulation patterns. The modern $\delta^{18}O_c$ range found in Wanxiang Cave (-6.7 to –8.1‰) is similar to the LGM range, however, suggesting that in modern samples, an increase in temperature may indeed lead to an increased $\delta^{18}O_c$. The discrepancy between $\delta^{18}O_c$-T relationships that appears to exist between modern and fossil speleothems from China indicates that caution must be used in interpreting oxygen isotopic composition of speleothems in terms of paleotemperature alone. Through our use of multiple proxies, we will better determine which of these factors are reflected in speleothems from Wanxiang Cave. Fluid inclusion analysis will provide direct evidence of the isotopic composition of paleowaters, which can then be used for detecting past changes in temperature (Dennis *et al*., 1998). In addition, studies of crystal morphology and growth band thickness can provide independent evidence about precipitation above the cave (Gonzalez *et al*., 1992; Baker *et al*., 1993).

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